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How efficient are market-based instruments in mitigating climate change in small emitter South Asian economies?

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ABSTRACT

This paper examines the effectiveness, efficiency, and economy-wide impacts of a carbon tax, fuel tax, and some policy mix options for Sri Lanka and Pakistan using their global commitments to reduce carbon emissions. The results indicate that the carbon tax is best for Sri Lanka to reduce emissions by 7% from 2010 levels. This policy shows the least welfare deteriorating effect with increases in real GDP by 0.2%. Although Pakistan has a distorted market of energy subsidies and taxes, the carbon tax is appropriate for emissions reductions of 5% from 2011 levels with no adverse impact on GDP. Thus, both economies can achieve their emission targets cost-effectively and any welfare loss can be compensated from the carbon tax revenues. However, a carbon tax is not a one size fits all climate change policy instrument given the associated cost effectiveness-efficiency trade off, and the countries' dependence on domestic and imported energy resources.

1. Introduction

The global climate has been changing continually since the pre-industrial era mainly due to high concentrations of anthropogenic greenhouse gasses (GHGs). Over the period 1750–2011, about half of the total anthropogenic carbon dioxide (CO_2) emissions were accumulated in the last 40 years. Increased economic and population growth have led to changing lifestyles, increased energy use, land use patterns, and all of these factors together with climate policy act as key drivers of anthropogenic GHG emissions (Pachauri et al., 2014). However, it has been agreed that failing to mitigate climate change will cause long lasting impacts for people and ecosystems. While climate change will have significant impacts on all countries, the poorest countries will suffer earliest and the most, although their contribution to past climate change effect has been the least (Stern et al., 2006).

The scientific findings (e.g., see Burniaux et al., 2008) show that global GHG emissions under a business as usual scenario (BAU) would double between 2008 and 2050. Consequently, the concentrations of CO_2 and GHGs will increase by about 525 parts per million (ppm) and 650 ppm CO_2 equivalent respectively in 2050 and will continue to rise after that. The resulting mean global temperatures would be about 2 °C higher in 2050 and 4-6 °C higher in 2100 compared to the temperatures in the pre-industrial era (ibid). Accordingly, the average cost of BAU climate change over the next two centuries will be equivalent to as much as 14.4% of global per capita consumption when both market and non-market impacts are incorporated (Stern, 2007).

The concerns about the devastating effects of global climate change and the consequences of inaction have led policymakers from around the globe to consider ways to mitigate GHG emissions. The new global agreement to combat climate change, the Paris Agreement, was adopted in December 2015 under the United Nations Framework Convention on Climate Change (UNFCCC). This agreement aims at holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit it to 1.5 °C (UNFCCC, 2015). To achieve this global target, individual countries have submitted Intended Nationally Determined Contributions (INDCs) outlining their climate change mitigation contributions post 2020. It is however up to the individual countries to consider the appropriate policy instruments that can be implemented nationally to meet GHG reduction targets in their INDCs while improving national welfare, efficiency, national output and employment.

Deciding on the right tools to reach emissions reduction targets in an effective and efficient manner is of vital importance. In this regard, Stern (2008) states that policies must be designed and applied carefully, and wherever possible, market-based solutions must be considered. Such solutions need to incorporate sector and country specific technologies and policy instruments to deal with different emission targets. In designing appropriate mitigation polices, it is also necessary to consider the three basic criteria: (i) Effectiveness, that is, achieving GHG emissions

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reduction of the required scale; (ii) Efficiency, that is, policies that can be implemented in the most cost-effective way with minimum adverse effect on GDP; and (iii) Equity, that is, consideration of the greater vulnerability of poor countries to the climate change impacts and responsibility of wealthy nations for the past emissions. Several studies such as Calderón et al. (2016), Vera and Sauma (2015), Alton et al. (2014) and Kim (2014) have shown that implementing a carbon tax to reduce emissions leads to a fall in GDP and thus the trade-off needs to be carefully managed.

The advantages of market-based instruments (MBIs) such as carbon taxes or tradable permits compared with regulation for emissions mitigation have been well documented in the literature. In recent times the fuel tax has been identified as an MBI that could be used for GHG abatement although it was originally designed for non-environmental reasons (e.g., see Datta, 2010). Also emerging on the policy front is a debate about the efficacy of using a policy mix as compared to the usual single policy strategy. Some studies have argued that using multiple policies is efficient for addressing environmental pollution problems (Börner et al., 2015; Lehmann, 2012; Twomey, 2012). However, other studies have pointed out challenges with implementing such policy mix strategies (Braathen, 2011; Sorrell and Sijm, 2003).

In the light of the issues highlighted above, the purpose of this study is to model GHG abatement policies for the South Asian economies of Sri Lanka and Pakistan, using MBIs (in the form of a carbon tax and a fuel tax), and to assess the effectiveness, efficiency, and the economy-wide impacts of the proposed instruments using a computable general equilibrium model (CGE) of energy and the environment. More specifically, the paper examines the following research questions considering their INDCs. First, what are the effects of a carbon tax and a fuel tax on the macroeconomy, the environment, and various sectors of these countries? Second, based on these impacts, is a carbon or fuel tax more effective in the implementation of the countries' INDCs? If not, why not? Third, is a mix of fuel and carbon taxes perhaps a better option? If so, what could be the optimal mix of these policies? In doing so, the study makes two important contributions to the literature. First, while previous studies have examined the impacts of either the carbon tax or fuel tax in isolation, none of them have considered the effects of these policies as part of a policy package as attempted here. Second, we consider the effectiveness of these policies in relation to the selected countries' achievement of their environmental goals as detailed in their INDCs. To the best of our knowledge, this is the first of such studies to be conducted for any south Asian country.

The findings from this study will have implications for other similar economies. Even though current GHG emissions in Sri Lanka and Pakistan are far below the global average, GHG emissions abatement is a major component in these countries' national climate change policies. Importantly, these economies will not remain as small emitters in the long run as a significant share of their future electricity generation is to be sourced from coal. Increased future GHG emissions from the coal-sourced energy production and transport sectors will have significant impacts on the economy and environment of these countries.

Both countries have submitted their INDCs to reduce GHG emissions post 2020. In the case of Sri Lanka, the INDC for mitigation aims to reduce GHG emissions against a BAU (2010) scenario by 20% in the energy sector (4% unconditionally and 16% conditionally[1]) and by 10% in the other sectors such as transport, industry, forests and waste (3% unconditionally and 7% conditionally) by 2030 (Ministry of Mahaweli Development and Environment of Sri Lanka, 2016). Pakistan's INDC commits to a 20% reduction in emissions by 2030 conditional on getting foreign aid to meet the total estimated abatement cost of US$40 billion (Government of Pakistan, 2016). Both countries have identified the energy and transport sectors to be priority considerations for GHG abatement policies.

[1] For example, with the assistance of rich countries, individual countries are less financially constrained and hence are able to (conditionally) increase their efforts to have high emission reduction targets. Thus, the unconditional emission reduction targets are lower due to the lack of such support.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature, with an emphasis on MBIs for GHG abatement. Section 3 describes the modeling framework which is based on the Energy-Environmental Version of the Global Trade Analysis Project (GTAP-E), the database used, and the simulated shocks for the analyses. The results of the study are presented and discussed in section 4 while section 5 concludes.

2. Literature review

Global climate change is a cost for the present as well as future generations. Firms, households, and governments are the components of the economic system who generate GHGs, which is the primary cause for climate change. However, the problem is that those who are responsible for these anthropogenic GHG emissions do not directly bear the costs as they do not take into consideration the cost of their emissions when they make production and consumption decisions. Pigou (1920) first suggested that these negative externalities can be internalized by a tax imposed by the government, which is equal to the marginal cost of emissions. The fundamental concept underlying MBIs is derived from the Pigouvian tax.

Two types of MBIs have been designed for GHG abatement: the emissions trading scheme (ETS) and the carbon tax. The former sets a limit on the amount of GHG emissions permitted, which is quantity based while the latter puts a price on emissions and is thus a price-based instrument. As a result of carbon or emission tax rates, emission-intensive goods will have higher market prices and/or lower profits. Thus, market forces adjust in a cost-effective way to minimize the emissions. More specifically, there are two types of incentive effects. The direct effect on increasing market prices encourages conservation measures, energy efficient investments, fuel and product switching, and alterations in the economy's production and consumption patterns. The indirect effect made possible by revenue recycling reinforces the above effects through changes in investment and consumption patterns (Baranzini et al., 2000).

It is argued that a carbon tax is the most cost-effective policy to reduce emissions. Stiglitz (2016) states that a high carbon price which is equivalent to the social cost of carbon emissions would help the world to achieve both the goal of limiting climate change and a significant investment to retrofit economies for global warming. Also, achieving the high carbon price through a carbon tax would generate a significant amount of revenue that can be used to address any adverse effects of the carbon tax. Generally, these taxes are easier to administer than personal or corporate taxes and are thus less likely to result in tax avoidance or evasion (Hammar and Sjöström, 2011; Shah and Larsen, 1992). Furthermore, there is an incentive for induced technical change, and if properly aligned with a carbon tax policy, a country could increase overall abatement than would be warranted in its absence (Goulder and Mathai, 2000). By and large, the empirical evidence shows that a carbon tax may be an attractive policy option in mitigating GHG emissions and that most of the adverse impacts may be offset by the design of the tax, and effective use of the generated tax revenues (see Freebairn, 2016; Baranzini et al., 2000).

Fuel taxes, on the other hand, were not originally designed for environmental purposes but they can have environmental effects. The literature shows that fuel taxes (or the removal of fuel subsidies) have affected growth in fuel demand and the associated CO_2 emissions. The experience of fuel taxes in Europe and Japan shows that this type of instrument can have significant environmental effects (Sterner, 2012). Calculating hypothetical transport demand in the OECD and using various fuel tax rates, Sterner (2007) shows that fuel taxes are the single most influential climate instrument implemented to date with a considerable reduction in overall carbon emissions even though it has not been given due attention in the policy debate. Others have highlighted that a fuel tax facilitates the internalization of externalities and improves resource allocation and welfare in an economy and has thus been referred to as an optimal tax (Parry et al., 2007; Innes, 1996). Theoretical justification and empirical evidence on the reduction of negative externalities using fuel taxes can be found in Spiller et al. (2014) and Li et al. (2014).

With discussion of the carbon tax, we summarise the findings for developing countries given our focus countries. Using the GTAP-E model, Kim (2014) found that despite some negative impacts of different carbon tax scenarios in Vietnam, there is a role for the carbon tax to promote new and renewable energy sources in the country. However, Coxhead et al. (2013) using a CGE model argue that such a carbon tax is likely to conflict with Vietnam's other development objectives as the poorest households will experience substantial losses. The adoption of the carbon tax was also seen to adversely affect Vietnam's global competitiveness for a broad range of products irrespective of their energy intensity. These losses will in turn impact negatively on jobs growth in the country.

Siriwardena et al. (2007) used an input-output decomposition technique to investigate the impact on economy-wide emissions due to carbon and energy taxes levied within the electricity supply sector in Sri Lanka. The study found changes in fuel mix in thermal power generation and final demand to be the main contributors in achieving mitigation. Moreover, there was a strong correlation between emissions reduction and the value of the price elasticity of electricity. However, the above study considered only the effects of a sector specific (i.e. power) carbon tax and thus the impacts of an economy-wide levied carbon tax in Sri Lanka remain unclear. For Indonesia, Yusuf and Resosudarmo (2015) found strongly progressive income distributive effects of a carbon tax in contrast to the regressive effects in most developed countries studies.

In most of the empirical literature, although the fuel tax has been studied for its income distributional effects and progressivity, studies on its contribution to emissions abatement are sparse, especially in developing countries. Comparing the fuel tax and food tax incidence in different expenditure groups of households in Ethiopia, Mekonnen et al. (2013) concluded that fuel tax in the country is not regressive. The results suggest that it could also achieve emissions abatement and foreign exchange savings through reductions in fuel consumed. Datta (2010) also found that a fuel tax in India would be progressive as would a carbon tax. Although there was no attempt to quantify emissions, the results provide some insights on emissions abatement through reduced demand for transportation fuels. Likewise, Agostini and Jiménez (2015) found the fuel tax in Chile to be moderately progressive on income distribution.

It has been suggested that both the carbon tax and fuel tax could be combined to form a policy mix for efficient carbon emissions control (Börner et al., 2015; Lehmann, 2012; Twomey, 2012). Lehmann (2012) put forward two rationales for using a policy mix strategy. These are the ability of a policy mix strategy to correct for multiple reinforcing failures of private governance structures (i.e. pollution externalities and technological spillovers), and the capability of implementing a policy mix to cope with high transaction costs resulting from the single first-best policies. For example, implementation of single emissions control policies in the presence of heterogeneous marginal pollution damages may lead to high transaction costs (ibid). On the other hand, Braathen (2011) highlights the risk of combining another policy if there is already an emissions control policy in place, because of the increased total costs of achieving stringent reduction targets. Moreover, Sorrell and Sijm (2003) point out that although a policy mix is theoretically possible, such a strategy could be difficult to implement because the governments may be reluctant to implement unfamiliar or untested policy alternatives. Furthermore, the inertia of existing instruments may make them difficult to displace. By and large, the lack of consensus on the effects of the carbon tax, fuel tax, and the policy mix in South Asian developing countries and their efficiency in GHG abatement represent a gap in the existing literature which this study seeks to fill.

3. The modeling framework

3.1. The GTAP-E model

The general equilibrium approach was selected over the partial equilibrium model due to the former's ability to capture economy-wide effects associated with the energy, environmental and economic linkages. In particular, we used the GTAP-E model developed by Burniaux and Truong (2002) and revised by McDougall and Golub (2007), together with the GTAP-E Database Version 9 (see Narayanan et al., 2015) for our analysis. A comparison of the CGE models available for analyzing climate change policies can be found in Kremers et al. (2002). That study compares each model with a set of distinct characteristics that are constructed to address aspects related to climate research, namely, the impact of climate policies on international trade, strategic issues regarding the timing of climate policies, and ecological issues.

The GTAP-E model is an extension of the standard GTAP model that introduces an energy-environmental dimension that is suitable for analyzing GHG issues and related policy scenarios. The structure of the GTAP-E model is fully documented in Burniaux and Truong (2002). The standard GTAP model is a comparative-static, multisector, multiregional CGE model, which assumes perfect competition and constant returns to scale. The model is based on national or regional input-output tables and it fully tracks bilateral trade flows between all the countries in the database. It relies on the standard neoclassical assumptions detailed in Burniaux and Truong (2002).

Firms maximize profits subject to a nested constant elasticity of substitution (CES) production function which combines primary factor endowments and intermediate inputs to produce final goods. Firms pay wages/rental rates to the household in return for the employment of factor endowments (land, labor, capital and natural resources). Firms sell their output to the other firms (as intermediate inputs), to private households, government, and to the global market. They export tradable commodities and import intermediate inputs from the other regions. Following the Armington assumption (Armington, 1969), goods are differentiated by their country of origin, and thus the model tracks bilateral trade flows (Hertel and Tsigas, 1997). The production structure of the standard GTAP model incorporates with an explicit capital-energy composite input to obtain the production structure of the GTAP-E model. Also, natural resources form a new endowment value-added nest. The capital energy composite also has the CES functional form. The energy nest is further disaggregated to a multilevel structure of electric and non-electric energy and further the non-electric nest to coal and non-coal inputs following Armington assumption (see Fig. A1 in the Appendix). The model contains two global sectors, a global bank and the other one related to the international transport activity.

The revised version of the GTAP-E has several advantages which are extremely useful for our study. Unlike the original model, CO_2 emissions are calculated using a bottom-up approach. Thus, it can be assumed that emissions are proportional to the energy consumption of firms, private households, the government, and both domestic and imported products. The carbon tax rate is a bloc level variable in the revised version that specifies both nominal and real rates and the relationship between them. The carbon and fuel tax policies cause changes in prices and quantities of energy and other commodities so that consumption and production patterns are altered in such a way as to minimize those effects. The production system has been altered in the revised version with more intermediate levels of nesting and combinations of using capital with energy.

3.2. Aggregated database and shocks

The GTAP-E data used in this study is based on the most recent GTAP 9 database and the extended energy balances are compiled by the International Energy Agency. The database provides CO_2 emissions data distinguished by fuel type and by user for each of the 140 regions in the database. We used the base year economy of 2011 (which is the latest available reference in the database) and combined 140 GTAP regions into 15 aggregates, and 57 GTAP commodity sectors into nine aggregates. The details of the regional and sectoral aggregation are shown in Table A1 in the Appendix.

We used the price homogeneous closure (as found in the standard GTAP closure) and the real carbon tax rate was treated as an exogenous carbon tax rate variable. The carbon tax is levied on the four GTAP-E

Table 1
Baseline fuel tax rates.

Country	Domestic Products		Imports	
	Oil products	Gas	Oil products	Gas
Sri Lanka	0	−0.5	0	0.04
Pakistan	37.78	10.14	37.78	−28.12

energy commodities, namely, coal, oil, gas, and oil products based on the carbon content of these commodities. The fuel tax was implemented by shocking the individual tax levers of oil products and gas. Since the fuel tax does not take into account the different carbon contents of each commodity, the applied tax rate is based on consumption and is the same for both domestic and imported commodities. The baseline carbon tax rate was taken to be zero for both countries as such a policy does not already exists. The baseline values for the percentage fuel tax rates are shown in Table 1.

First, we analyzed separately the effects of the carbon and fuel tax options in achieving the GHG mitigation targets specified in the INDCs of the two economies. Sri Lanka has clearly defined its unconditional emissions reduction target as 7% from the BAU level and this is used in the simulations. However, in the case of Pakistan as there are no clear goals in the INDCs as such, we conservatively assume an emissions reduction of 5% to make the analysis comparable with Sri Lanka. We then used several policy mix options of carbon and fuel tax to compare those with the single policy strategies of either the carbon or fuel tax applied before.[2] Table 2 sets out the various policy scenarios considered.

4. Results and discussion

This section discusses the simulation results of the tax incidence for Sri Lanka and Pakistan separately. It first presents the base year CO_2 emissions followed by the emission reductions, macroeconomic, sectoral, and employment impacts in the counterfactual scenario with various tax policy options. The base year CO_2 emissions are summarized in Fig. 1. It can be seen that consumption of oil products is the primary source of CO_2 emissions in Sri Lanka, accounting for almost 16.6 million tons (Mt) of CO_2 out of 18.07 $MtCO_2$ (i.e. 91%) of total emissions. On the other hand, coal contributes only 1.47 $MtCO_2$ to the total emissions. Firms' consumption of oil products, both domestic and imported, contribute approximately three-fourth of emissions from oil products while private consumption contributes to only one-fourth of emissions.

Pakistan's emissions in 2011 accounts for 130.33 $MtCO_2$ with significant shares of emissions from oil products (60.32 $MtCO_2$) and gas (54.6 $MtCO_2$). Almost 82% of these emissions are due to the consumption of domestic and imported oil products and domestic gas products by firms. Coal also contributes to approximately 12% (15.41 $MtCO^2$) of the country's emissions which is entirely due to firms' consumption. In 2010–2011 natural gas and oil were the two main sources of primary energy supply in Pakistan with shares of 48% and 32%, respectively.

4.1. Results for Sri Lanka

4.1.1. Emissions abatement under mitigation taxes

The tax incidence consists of levying the taxes at the rates shown in Table 2. Table 3 reports the impacts of each scenario on CO_2 emissions abatement and energy prices. The results highlighted in bold in Table 3 indicate that a carbon tax of US\$27/tCO_2 or a fuel tax of 12% levied on gas and oil products will keep Sri Lanka on track to achieve its unconditional emissions mitigation target of 0.94 $MtCO_2$ specified as a 7% reduction in the INDCs. A policy mix combining a carbon tax of US\$15/tCO_2 and a fuel tax of 5% on gas and oil products is also able to attain the target.

Table 2
Simulation scenarios.

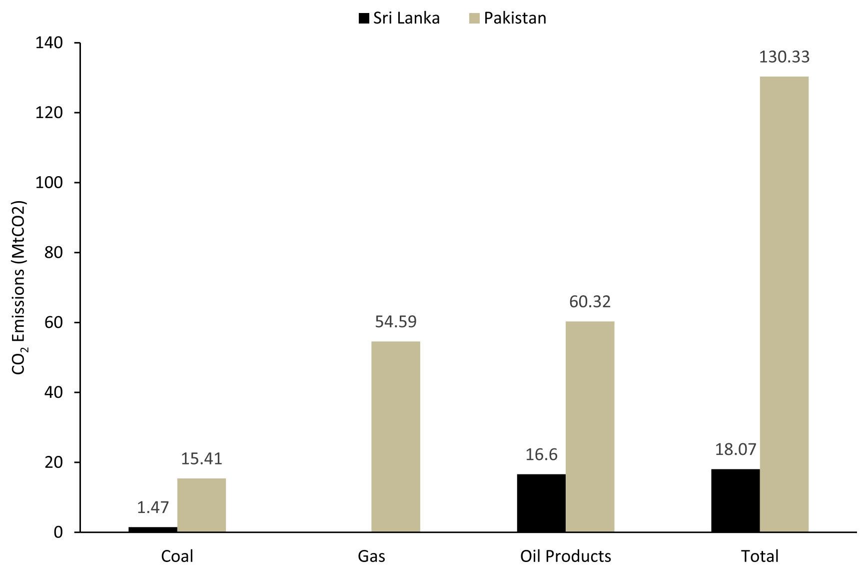
Country	Policy Scenario		Scenario Description
Sri Lanka	Carbon Tax	CTax20	Carbon tax of US\$20/tCO_2
		CTax27	Carbon tax of US\$27/tCO_2
		CTax30	Carbon tax of US\$30/tCO_2
	Fuel Tax	FTax10	Fuel tax of 10% on gas and oil products
		FTax12	Fuel tax of 12% on gas and oil products
		FTax15	Fuel tax of 15% on gas and oil products
	Policy Mix	CF10_10	Carbon tax of US\$10/tCO_2 and fuel tax of 10% on gas and oil products
		CF5_10	Carbon tax of US\$5/tCO_2 and fuel tax of 10% on gas and oil products
		CF15_5	Carbon tax of US\$15/tCO_2 and fuel tax of 5% on gas and oil products
Pakistan	Carbon Tax	CTax10	Carbon tax of US\$10/tCO_2
		CTax13	Carbon tax of US\$13/tCO_2
		CTax15	Carbon tax of US\$15/tCO_2
	Fuel Tax	FTax10	Fuel tax of 10% on gas and oil products
		FTax12	Fuel tax of 12% on gas and oil products
		FTax15	Fuel tax of 15% on gas and oil products
	Policy Mix	CF5_5	Carbon tax of US\$5/tCO_2 and fuel tax of 5% on gas and oil products
		CF2_10	Carbon tax of US\$2/tCO_2 and fuel tax of 10% on gas and oil products
		CF10_10	Carbon tax of US\$10/tCO_2 and fuel tax of 10% on gas and oil products

For a country whose consumption of oil products generates over 90% of CO_2 emissions, the fuel tax appears to be a powerful instrument in emissions abatement showing the greatest percentage reduction in emissions. The emission reductions brought about by the three policies are due mainly to demand and price changes. In some cases, a slight increase in emissions from coal can be seen due to the substitution effect. The fuel tax is associated with a greater increase in the prices of gas (11%) and oil products (12%) and hence there is a shift to coal and oil since these substitutes are lower in price. Hence with the fuel tax, electricity prices register the highest increase in the counterfactual scenario compared to the carbon tax and the policy mix strategies.

In contrast, the carbon tax reduces emissions from both coal and oil products. In the carbon tax scenario of CTax 27 which enables the emission reduction target to be reached, this results in the greatest increase in coal and gas prices (57% and 16% respectively) and the lowest increase in the prices of oil products (8%) and electricity (6%) compared to the respective fuel tax and policy mix strategies. Sri Lanka's energy shares in 2015 indicate that 42% of its energy generated is thermal based, from which 34% is generated through coal-fired plants and the rest is from oil-based plants. It is however a concern that the energy share plan highlights the prospect of increasing the share of coal-based thermal up to 51% in 2030 (Ceylon Electricity Board, 2015). In this (future) scenario, a carbon tax will be effective compared to the fuel tax as the former applies to all the energy commodities so that future electricity prices and demand are adjusted appropriately to the source of the electricity generation mix. When carbon and energy taxes are imposed specifically in Sri Lanka's electricity supply industry, Siriwardena et al. (2007) conclude that the fuel mix in thermal electricity generation and the final demand effects are the major factors contributing to overall emissions reduction. Changes in electricity generation composition also result in a decrease in electricity demand due to higher electricity prices.

The policy mix strategy which enables the specified mitigation target to be reached, results in emissions reduction from both coal and oil products, with a higher share of abatement from oil products. This strategy is also associated with higher energy prices and the electricity price increase lies between the fuel and carbon tax options. The combination of a smaller share of fuel tax (5%) which is a powerful instrument in emissions mitigation, with a larger proportion of carbon tax (US\$15/tCO_2) is an effective strategy for Sri Lanka for two reasons. First, this strategy

[2] The specific tax rates were computed using backward iteration. We first calculated a country's unconditional target from 2010 levels in $MtCO_2$. We then calculated the tax rate (carbon and fuel) required to achieve this target.



Note: The CO_2 emissions from oil for Pakistan are however negligible at 0.01.

Fig. 1. Base year CO_2 emissions.

Table 3
Impact on CO_2 emissions and energy prices.

Sri Lanka		Carbon Tax			Fuel Tax			Policy Mix		
		CTax 20	CTax 27	CTax 30	FTax 10	FTax12	FTax15	CF 10_10	CF 5_10	CF 15_5
CO_2 Emissions (% Change)	Coal	−16.05	−20.08	−21.64	0.29	0.38	0.52	−8.87	−4.62	−12.8
	Oil	−13.46	−16.36	−17.44	1.6	1.88	2.28	−6.94	−3.13	−10.46
	Gas	−8.66	−11.28	−12.35	−4.31	−5.18	−6.52	−8.37	−6.4	−8.36
	Oil products	−2.90	−3.86	−4.27	−4.87	−5.76	−7.04	−6.17	−5.53	−4.62
	Total	−3.97	**−5.18**	−5.68	−4.46	**−5.26**	−6.42	−6.39	−5.45	**−5.28**
CO_2 Emissions Abatement ($MtCO_2$)	Coal	−0.24	−0.30	−0.32	0.00	0.01	0.01	−0.13	−0.07	−0.19
	Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Oil products	−0.48	−0.64	−0.71	−0.81	−0.96	−1.17	−1.02	−0.92	−0.77
	Total	−0.72	**−0.94**	−1.03	−0.81	**−0.95**	−1.16	−1.15	−0.98	**−0.95**
Energy Price Index (% Change)	Coal	41.93	56.61	62.91	−0.34	−0.4	−0.49	20.64	10.15	31.28
	Oil	−0.22	−0.30	−0.33	−0.35	−0.41	−0.51	−0.45	−0.4	−0.34
	Gas	12.09	16.33	18.15	9.13	11	13.79	15.2	12.16	13.55
	Oil products	5.69	7.68	8.54	10.06	12	14.9	12.91	11.48	9.48
	Electricity	4.79	6.43	7.13	7.41	8.67	10.54	9.82	8.62	7.86
Pakistan		**Carbon Tax**			**Fuel Tax**			**Policy Mix**		
		CTax 10	CTax 13	CTax 15	FTax 10	FTax 12	FTax 15	CF 5_5	CF 2_10	CF 10_10
CO_2 Emissions (% Change)	Coal	−11.31	−14.13	−15.89	−2.04	−2.46	−3.08	−6.96	−4.53	−13.07
	Oil	0.31	0.4	0.45	3.81	4.63	5.84	1.85	3.84	3.99
	Gas	−5.36	−6.89	−7.89	−8.09	−8.86	−9.98	−8.62	−9.07	−12.78
	Oil products	−1.10	−1.42	−1.63	−1.74	−2.61	−3.87	−0.02	−1.95	−2.77
	Total	−4.09	**−5.22**	−5.94	−4.44	**−5.21**	−6.34	−4.44	**−5.23**	−8.18
CO_2 Emissions Abatement ($MtCO_2$)	Coal	−1.74	−2.18	−2.45	−0.31	−0.38	−0.47	−1.07	−0.70	−2.01
	Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Gas	−2.93	−3.76	−4.31	−4.42	−4.84	−5.45	−4.71	−4.95	−6.98
	Oil products	−0.66	−0.86	−0.98	−1.05	−1.57	−2.33	−0.01	−1.18	−1.67
	Total	−5.33	**−6.80**	−7.74	−5.79	**−6.79**	−8.26	−5.79	**−6.82**	−10.66
Energy Price Index (% Change)	Coal	20.33	26.4	30.43	0.57	0.54	0.49	10.85	4.65	20.91
	Oil	−0.08	−0.1	−0.11	0.26	0.14	−0.04	0.55	0.25	0.21
	Gas	7.01	9.19	10.66	11.13	12.97	15.75	10.18	12.6	18.58
	Oil products	3.11	4.04	4.67	4.14	5.98	8.74	1.07	4.75	7.23
	Electricity	1.92	2.49	2.88	4.89	5.75	7.03	3.71	5.28	6.83

Note: Figures in bold indicate the policy option that provides emissions reduction closest to the targets.

provides the most effective mitigation of emissions from a highly consumed energy commodity at present. Second, it has greater flexibility to adjust future electricity demand as a result of a prospective future generation mix that will rely on coal. However, the associated macroeconomic and sectoral effects also need to be considered apart from the emission reductions potential, before determining the optimal policy.

4.1.2. Macroeconomic impacts

In this section, the macroeconomic effects seen in Table 4 of the three selected policy scenarios that can achieve the emissions reduction target

Table 4
Macroeconomic impacts.

	Sri Lanka			Pakistan		
	Carbon Tax	Fuel Tax	Policy Mix	Carbon Tax	Fuel Tax	Policy Mix
	CTax27	FTax12	CF15_5	CTax13	FTax12	CF2_10
GDP (% Change)	0.19	0.28	0.23	0	−0.35	−0.41
Private Consumption	0.21	0.30	0.25	0.01	−0.36	−0.42
Investment	−1.59	−2.30	−1.90	−1.66	−2.99	−2.84
Government Expenditure	0.26	0.36	0.30	0.07	−0.36	−0.44
Exports	−0.25	−0.36	−0.30	0.53	1.07	1.21
Imports	−1.33	−1.92	−1.58	−0.48	−0.96	−0.83
CPI (% Change)	0.35	0.5	0.41	0.08	−0.32	−0.39
Trade Balance (US$ million)	272.17	390.11	321.77	434.66	878.94	845.62
Tax Revenues (US$ million)						
Carbon Tax Revenue	489.44	0	272.06	1695.61	0	259.64
Other Tax Revenue (includes fuel tax)	15.57	22.3	18.74	0.8	−18.44	−21.82
Welfare (EV measured in US$ million)	−43.24	−61.67	−47.93	−105.43	−50.45	−45.68
Allocative Efficiency Effects	−52.46	−75.21	−58.78	−39.07	76.09	96.59
Terms of Trade Effects	5.42	7.66	6.45	−26.34	−60.29	−69.52
Output Change Effect	−20.02	−29.46	−23.4	0	0.01	0.01

of 0.94 $MtCO_2$ are compared. The objective of this section is to find the optimum CO_2 abatement policy for Sri Lanka. The results indicate that all three tax policies lead to small percentage increases in GDP relative to the baseline. The carbon (fuel) tax results in a GDP increase of 0.19% (0.28%) and 0.23% increase with a policy mix strategy. The GDP decomposition shows that consumption and government expenditure components increase with the tax policies while investment, exports, and imports decline but with an improvement in net exports. The fuel tax is associated with the largest decrease in investment and the greatest increase in consumption, government expenditure, and net exports, and hence results in the highest GDP growth.

The increase in GDP following the imposition of the energy taxes can be explained as follows. The initial effect of the taxes is a reduction in energy consumption by households and producers. Given that Sri Lanka is an energy importer, this results in a decline and hence an improvement in the trade balance. For example, the fuel tax improves the trade balance by US$390 million while the improvement in the case of the carbon tax is US$272 million (see Table 4). Although the manufacturing sector declines, this is somewhat offset by increases in the outputs of agriculture and forestry which now shift from using an expensive input (energy) to a cheaper one (e.g., labour). The increases in the outputs of agriculture and forestry improve household incomes, which in turn lead to increased consumption expenditures.[3] The net effect of the improvement in the trade balance and the increased output in agriculture and forestry is a net increase in GDP. These results are consistent with those of Gupta and Mahler (1995) who showed that levying a tax especially on petroleum results on the conservation of foreign exchange due to reduced imports.

Undoubtedly, taxation especially on energy commodities is a cost to producers and so affects their profits. They pass this burden to consumers through increased prices of goods, which is reflected by an increase in the consumer price index (CPI). In this case the fuel tax causes the highest increase in the CPI (0.5%), followed by the policy mix strategy (0.41%) and the carbon tax (0.35%). This can be explained by the sectoral changes in prices shown in Table 5. The fuel tax is associated with the highest increase in electricity prices (9.11%) which explains the rise in the CPI. Moreover, a significant share of electricity generated is thermal based using coal, oil, and oil products.[4] Overall, it appears that the carbon tax has the least inflationary effect relative to the fuel tax and policy mix option.

The carbon tax is arguably a more attractive option given its revenue generating capacity and thus can be viewed as an effective policy to compensate losers. This study shows that the carbon tax (policy mix) would raise about US$489 (US$272) million in revenue (see Table 4). The biggest share of the revenue comes from Sri Lanka's most consumed energy commodity which is oil products. The revenue from the fuel tax is accounted for under the other indirect taxes and it is lower than the carbon tax.

Table 4 also shows the welfare effects associated with the tax policies. The welfare measurement used in GTAP-E is given by the equivalent variation (EV) which is expressed in millions of US$ in constant 2011 prices for all the households. The EV offers a money-metric measure of the total household income at constant prices that is equivalent to the proposed change. The carbon tax results in the lowest welfare deterioration (US$43 million) in the counterfactual scenario while the fuel tax causes the biggest loss (US$62 million). For all three tax options, the largest share of welfare loss is due to allocative inefficiency as a result of the movement of inputs from high marginal value product sectors to low marginal value product sectors (see Huff and Hertel, 2000). For example, due to substitution away from cheaper inputs (now being taxed) to the more expensive alternative inputs, there is an increase in the cost of production and hence marginal value product is lowered in those sectors.

The changes in the relative price of commodities due to the tax on production cost, affects households' consumption behavior. For example, the increased price of electricity and energy- intensive goods due to tax policies would have an uneven effect on households based on their usage and income status. Even though there is an increase in household income (of 0.21%, not shown here), the share of income spent on electricity and energy-intensive goods may be greater (given that electricity consumption is relatively price inelastic) for low income households, causing increased consumption expenditures and varying effects on welfare.

4.1.3. Sectoral impacts and employment effects

In regard to the tax policy scenarios, Table 5 shows that the changes in sectoral output are determined by their emissions intensity. That is, the industries with higher emissions intensity are the sectors whose outputs decline, and prices rise the most. This is most drastic with the fuel tax while the carbon tax is associated with the least output deterioration and the minimum price rise in oil, oil products, electricity, energy-intensive industries, and other industries and services. The agriculture and forestry sectors on the other hand experience positive output changes due to movement of inputs away from the energy-intensive sectors into these sectors.

The oil products sector contributes the most to the improvements in the trade balance in all the policy options followed by oil and other industries and services. This is because of the larger contractions in imports of these products in response to the levied taxes. Sri Lanka has no coal or oil reserves and is entirely dependent on energy imports. The fuel tax shows the highest improvements in the trade balance. However, considering that it has the least adverse effects on the sectoral outputs

[3] The agriculture and forestry sectors together contributed 11.2% of Sri Lanka's GDP in 2011.

[4] Sri Lanka's thermal based electricity generation is 62% in 2014, available at www.info.energy.gov.lk.

Table 5
Sectoral impacts.

Sri Lanka	Output (% Change)			Prices (% Change)			Contribution to Trade Balance (US$ million)		
	Carbon Tax CTax27	Fuel tax FTax27	Policy Mix CF15_5	Carbon Tax CTax27	Fuel tax FTax27	Policy Mix CF15_5	Carbon Tax CTax27	Fuel tax FTax27	Policy Mix CF15_5
Agriculture	0.05	0.07	0.06	−0.29	−0.42	−0.34	22.39	31.97	26.23
Forestry	0.14	0.19	0.16	−0.58	−0.83	−0.68	0.82	1.18	0.97
Coal	−19.15	0.83	−11.81	−2.71	−0.4	−1.72	13.92	−0.26	8.87
Oil	−0.28	−0.87	−0.63	−0.54	−1.21	−0.91	49.33	113.11	85.68
Gas	−10.89	5.14	−8.13	0.18	−0.34	−0.06	0	0	0
Oil products	−3.01	−6.9	−5.22	0.07	0.1	0.08	141.87	171.55	142.82
Electricity	−2.67	−3.29	−3.36	6.73	9.11	8.22	−0.01	−0.01	−0.01
Energy Intensive Industries	−0.84	−1.07	−1.01	0.23	0.28	0.28	2.65	17.9	7.84
Other Industries and Services	−0.4	−0.59	−0.47	0.06	0.09	0.07	41.18	54.69	49.39
Pakistan	**Output (% Change)**			**Prices (% Change)**			**Contribution to Trade Balance (US$ million)**		
	Carbon Tax CTax13	Fuel tax FTax12	Policy Mix CF2_10	Carbon Tax CTax13	Fuel tax FTax12	Policy Mix CF2_10	Carbon Tax CTax13	Fuel tax FTax12	Policy Mix CF2_10
Agriculture	−0.08	−0.15	−0.12	−0.11	−0.27	−0.27	21.08	48.9	47.62
Forestry	−0.55	−0.66	−0.61	−0.76	−1.26	−1.22	1.37	2.1	2.01
Coal	−8.89	−3.22	−4.02	−0.34	0.42	0.27	85.19	11.72	25.19
Oil	−0.81	−1.27	−1.09	−0.27	−0.81	−0.69	108.26	263.43	224.18
Gas	−6.66	−8.65	−8.78	−1.28	−1.76	−1.8	0.28	0.62	0.62
Oil products	−1.81	−4.21	−3.58	0.09	0.41	0.36	101.57	112.61	48.46
Electricity	−0.4	−3.92	−3.79	2.51	5.35	4.81	−1.42	−2.12	−1.81
Energy intensive industries	−2.53	−2.89	−2.77	1.32	1.35	1.28	−387.15	−374.7	−357.92
Other industries and services	−0.18	−0.36	−0.32	−0.22	−0.34	−0.37	505.48	816.38	857.25

and prices, the carbon tax would be the more appropriate policy followed by the policy mix strategy.

Table 6 shows that the majority of sectors experience employment losses in the counterfactual scenario under all three tax policy regimes. For most of the industries, the losses in the skilled labor category exceed that of unskilled labor. The sectors that are highly exposed to the tax show larger job losses. In sectors such as oil, oil products, energy-intensive industries, and other industries and services, the loss is minimum with the carbon tax than the fuel tax. With the electricity sector, as it is price inelastic, although there may be a decrease in demand, the overall GDP value of this sector will rise as the increase in price of electricity outweighs the contraction in its demand. In addition, more labour is substituted for the expensive carbon intensive inputs, leading to employment creation in the electricity sector (similar to results obtained by Siriwardena et al., 2007) under all tax policies with larger benefits under the fuel tax. Overall, the average wage declines under all the tax scenarios with the least adverse effects given by the carbon tax.

4.2. *Results for Pakistan*

4.2.1. *Emissions abatement under mitigation taxes*

We used various levels of the carbon tax, fuel tax, and policy mix strategies to find the necessary levels for each policy that Pakistan could adopt to achieve the assumed emissions mitigation target of 5% of 2011 levels which is approximately 6.5 $MtCO_2$. As seen in Table 3, either a carbon tax of US$13/$tCO_2$, a fuel tax of 12% or a policy mix strategy combining a carbon tax of US$5/$tCO_2$ and a fuel tax of 10% are comparable emissions reduction strategies. Both the carbon and fuel tax show higher emissions reduction from gas than oil products. The carbon tax is associated with the largest percentage increase of coal prices (26%) while the fuel tax caused the highest rate increase of gas (13%), oil products (6%), and electricity (6%) prices. As expected, the price changes with the policy mix strategy lies between those of the carbon and fuel taxes.

4.2.2. *Macroeconomic impacts*

Pakistani firms and consumers enjoy a range of subsidies on coal, electricity, oil, and gas products but face a high tax on private consumption of oil products as seen in Tables A2 and A3 in the Appendix. Thus, it can be said that Pakistan has a distorted energy market. Table 3 shows that when a fuel tax is applied, firms are still seen to enjoy the subsidies they had for coal and electricity, and households still benefit from the existing coal, oil, and electricity subsidies. However, with the carbon tax, the private consumption subsidy on coal is converted to a tax while the levels of subsidy on oil and electricity decrease. Firms on the other hand lose the previous coal subsidies and the level of subsidy on electricity declines. Pakistan also has a high ad valorem tax of 38% on private consumption of both domestic and imported oil products. With the set fuel tax rate to achieve the required emissions reduction, the tax level Pakistan had on oil products declines in the counterfactual scenario.

Table 4 shows that in the case of Pakistan, reducing CO_2 emissions has a cost in terms of GDP for the fuel tax and the policy mix strategies compared to the baseline scenario. For a 5% decline in emissions, GDP declines by 0.35% with the fuel tax and 0.41% with the policy mix strategy. However, with a US$13/$tCO_2$ carbon tax, GDP does not change in the counterfactual scenario. The decomposition of GDP shows that except for exports, consumption, investment, government expenditure, and imports all fall with the fuel tax and policy mix strategy. Since household incomes fall by 0.36% with the fuel tax and by 0.42% with the policy mix strategy, private consumption expenditure is seen to decrease. There is also a decline in the rental rate of capital which leads to a fall in investment in all the tax scenarios. Government spending too decreases with the fuel tax and the policy mix strategy, and more so for the latter. With the carbon tax, private consumption, government spending, and exports rise with a slight fall in investment. Household income rises with the carbon tax allowing more spending for consumption. Also, since poor households[5] cannot adjust to the increased energy prices by product switching or by any other mechanism, the share of expenditure on consumption increases with the increased prices.

The tax incidence in Pakistan improves the trade balance in all the

[5] Pakistan's poverty head count ratio based on its national poverty line is 36.3% of the population in 2011 (World Bank, 2016).

Table 6
Labor Market Effects (Percentage change).

	Sri Lanka						Pakistan					
	Carbon Tax		Fuel Tax		Policy Mix		Carbon Tax		Fuel Tax		Policy Mix	
	CTax27		FTax12		CF15_5		CTax13		FTax12		CF2_10	
	Skilled	Unskilled	Skilled	Unskilled	Skilled	Unskilled	Skilled	Unskilled	Skilled	Unskilled	Skilled	Unskilled
Average wages	−0.16	−0.19	−0.23	−0.26	−0.19	−0.21	−0.45	−0.38	−0.71	−0.65	−0.72	−0.65
Employment												
Agriculture	0	0	−0.01	0	0	0	−0.08	−0.09	−0.13	−0.15	−0.1	−0.12
Forestry	0.05	0.05	0.06	0.07	0.06	0.06	−0.67	−0.68	−0.85	−0.86	−0.79	−0.8
Coal	−35.03	−34.98	−1.69	−1.57	−22.96	−22.88	−58.56	−58.67	−24.18	−24.35	−29.26	−29.45
Oil	−0.89	−0.88	−2.28	−2.27	−1.69	−1.68	−2.43	−2.46	−3.92	−3.94	−3.36	−3.39
Gas	−10.89	−10.89	−5.14	−5.14	−8.13	−8.13	−7.44	−7.45	−9.62	−9.63	−9.77	−9.78
Oil products	−2.7	−2.67	−6.48	−6.45	−4.87	−4.84	−1.18	−1.26	−2.83	−2.9	−2.25	−2.33
Electricity	6.18	6.21	8.66	8.7	7.39	7.42	4.85	4.76	6.7	6.63	5.88	5.79
Energy intensive industries	−0.27	−0.25	−0.35	−0.32	−0.33	−0.31	1.16	1.09	1.25	1.2	1.27	1.2
Other industries and services	−0.03	0	−0.04	0	−0.04	0	−0.02	−0.12	−0.03	−0.11	−0.03	−0.12

scenarios. The fuel tax improves the trade balance by US$879 million, compared to US$846 million with the policy mix strategy. Pakistan is primarily dependent on oil and gas to fulfill its energy requirement. Since its domestic oil reserves are not sufficient to satisfy the demand, it imports larger quantities of oil and oil products from the Middle East. Therefore, the improvement in the trade balance is brought about mainly by the import reductions in the oil and oil product sectors (see Table 5 for the sectoral contributions). The fuel tax is also associated with the largest decrease in the percentage of the volume of imports.

It can be seen in Table 4 that the fuel tax and policy mix strategies lead to a slight decrease in CPI while the carbon tax causes a modest increase in inflation. This is because the fuel tax and policy mix strategy led to a decline in prices of most of the sectors such as agriculture, forestry, oil, and other industries and services, compared to the carbon tax policy. The decline in market prices of commodities is also contributed to by the existing subsidies in the baseline scenario. For example, agriculture, forestry, and other industries and services enjoy an electricity subsidy on both domestic and import purchases. Furthermore, there are private consumption subsidies on coal, oil, gas, and electricity for both domestic and import consumptions. Lowering the existing ad valorem tax rate on private consumption of oil products causes a decline in prices of final commodities in the counterfactual scenario.

The carbon tax generates revenue of approximately US$1696 million (Table 4) while the policy mix strategy generates US$260 million. It can be seen that the revenue from indirect taxes is negative for both the fuel tax and policy mix strategy, implying that overall the country still enjoys subsidies rather than taxes. For example, both the fuel tax and policy mix strategies lead to a reduction of the ad valorem tax rate for private consumption of oil products. However, the carbon tax converts the existing subsidy on private consumption of coal into a tax in the counterfactual scenario, resulting in increased revenue from indirect taxes.

Table 4 also shows that the policy mix strategy is associated with the least welfare deterioration (US$46 million) followed by the fuel tax (US$50 million). However, the carbon tax results in the largest welfare deterioration (US$105 million) in the counterfactual scenario. In all the scenarios, there are greater terms of trade losses with more significant effects under the policy mix strategy. Therefore, it is the loss of allocative efficiency associated with the carbon tax that explains the welfare deterioration. As the carbon tax is levied on all energy commodities (i.e. coal, oil, gas, and oil products), it reduces the demand for all these products resulting in a decline in production. Also, the industry output of coal declines (by 9%) compared to the fuel and policy mix strategies. This is because Pakistan uses a significant amount of coal given that coal accounts for approximately 12% of its base year emissions. Therefore, the allocative efficiency loss may stem from resource misallocation from the higher marginal value product sectors to relatively lower marginal value product sectors. Conversely, the fuel and policy mix strategy register gains in allocative efficiency although they are not large enough to completely offset the other losses contributing to a deterioration in welfare.

4.2.3. Sectoral and employment effects

Tables 5 and 6 show the effects of the tax policy scenarios considered here on output, prices, contributions to the improvement in the trade balance, and employment. Overall, the industries most affected are those with a higher dependence on energy, i.e. coal, gas, electricity, and energy-intensive industries. The policy mix strategy is associated with the least output reduction in coal mining and other industries and services and minimum price rise in energy-intensive industries. The carbon tax results in minimum effects on the output of all the other sectors except coal, minimum price reductions in agriculture, forestry, oil, gas, and other industries and services, and minimum price rise in oil products and electricity. Therefore, the carbon tax has less distortionary effects for a country like Pakistan where the agriculture and forestry sectors accounted for nearly 21% of GDP and about 44% of employment in 2014–15.

The decline in the output of the energy-intensive industries leads to a negative trade balance in this sector. The other industries and services is however the sector that contributes most to improvements in the trade balance with some significant contributions from oil, oil products, and agriculture (results not shown here but available upon request). The carbon tax is associated with the smallest wage decreases as seen in Table 6. It also shows the lowest declines in labor demand in most of the sectors, e.g. agriculture, forestry, oil, gas, oil products, and other industries and services compared to the other two tax options.

5. Conclusions

This study analyzed the emissions abatement potential, macroeconomic, sectoral, and employment effects of three emission reduction policies, namely, a carbon tax, a fuel tax, and a policy mix strategy to reduce CO_2 emissions in Sri Lanka and Pakistan using the GTAP-E model. Our results indicated that any of the following − a carbon tax of US$27/$tCO_2$, a fuel tax of 12% levied on gas and oil products, a policy mix combining a carbon tax with US$15/$tCO_2$ and a fuel tax of 5% − would keep Sri Lanka on track to achieve its unconditional emissions mitigation target of 7% as specified in its INDCs. For Pakistan, a carbon tax of US$13/$tCO_2$ or a fuel tax of 12% or a policy mix strategy combining a carbon tax of US$5/$tCO_2$ and a fuel tax of 10% would result in an emissions reduction of 5% from BAU levels.

The fuel tax compared to carbon tax performs well in terms of output expansion, conservation of foreign exchange, and improvement in the trade balance for Sri Lanka. However, unlike the fuel tax, the carbon tax has the greatest fiscal benefit, raising tax revenues by 0.77% of GDP in 2030 (approximately US$505 million) with a modest tax scenario (USD27/tCO_2). It also results in less inflation and has the smallest welfare deteriorating effect (0.07% loss of GDP in 2030 compared to 0.09% loss associated with the fuel tax). The direct gain in GDP related to the carbon tax is worth approximately

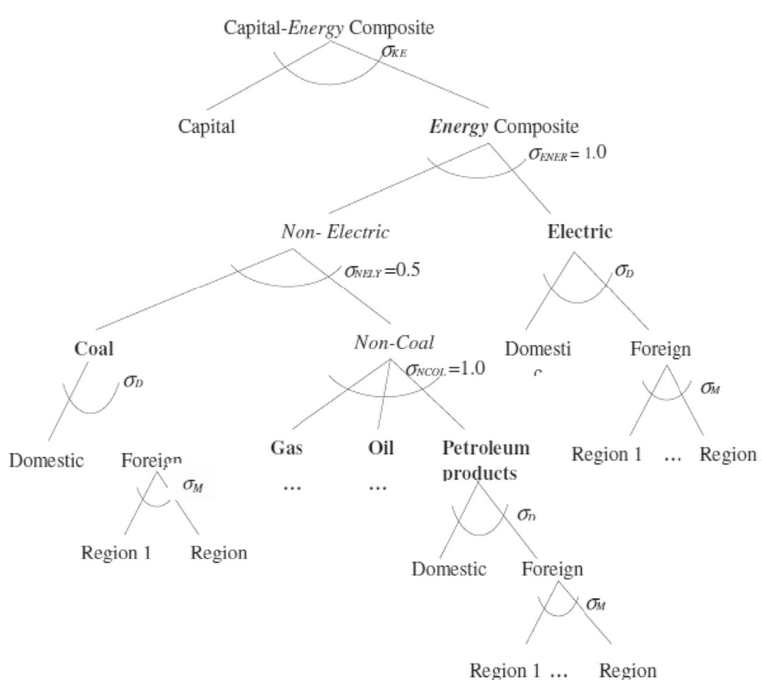
US$124 million compared to that of US$183 million with the fuel tax. The carbon tax also shows minimum adverse effects on other macroeconomic variables compared to the fuel tax and policy mix options. The performance of the policy mix strategy lies in between the two policy instruments. In terms of efficiency (or a cost-effective way of implementing policy) given by the changes in GDP, the carbon tax (fuel tax) results in the highest net gains, which is worth approximately US$586 million (US$144 million) in 2030. Hence the study concludes that the carbon tax is the best option for Sri Lanka with the net gain in GDP. Moreover, it has the greater flexibility to adjust future electricity prices caused by the potential generation mix of more coal use so that the future emission mitigation can be guaranteed.

For Pakistan, an economy with market distortions of subsidies and taxes, the fuel tax allows firms and households to still enjoy some subsidies in the counterfactual scenario. However, with the carbon tax, the private consumption subsidy on coal becomes a tax while the levels of subsidy on oil and electricity decline in the counterfactual scenario. Firms lose the subsidies they had for coal before, and the subsidies on electricity declined. The macroeconomic impacts indicated the potential role of the carbon tax in emissions mitigation without any cost in terms of GDP compared to the other policy options. Given that the carbon tax generates as much as US$1696 million revenue (approximately 0.79% gain in GDP on 2030) and has the smallest adverse effects in terms of output declines in agriculture, forestry, oil, gas, and other industries and services, this study finds it to be the least distortionary and has highest net gains in GDP for Pakistan. With less inflationary effects on electricity and oil products, and less wage decreases, coupled with minimum output reduction in the production sector, the carbon tax has less adverse impacts on poor households. Therefore, based on the criteria of cost-effectiveness and minimum distortionary effects, the carbon tax is found to be the optimum policy for Pakistan also. In addition, a carbon tax would be effective in discouraging future use of its domestic coal reserves.

For both countries which are low middle income, our analysis confirms that the carbon tax is best implemented in the most cost-effective way, with net GDP gains. Although Sri Lanka shows losses in real GDP, there is no change in real GDP with the carbon tax in the case of Pakistan. The result for Pakistan is therefore in contrast to the findings of a decline in real GDP resulting from a carbon tax in Vietnam (Kim, 2014) also a low middle income country, in developed countries such as Australia (see Asafu-Adjaye and Mahadevan, 2013; Siriwardana et al., 2011) and countries such as Colombia, South Africa, and Chile, which are upper middle income or better (see Calderón et al., 2016; Vera and Sauma, 2015; Alton et al., 2014). Therefore, research needs to be undertaken for countries with different levels of development for a more informed debate on appropriate climate change policies and the potential of a policy mix, the latter being absent in most previous studies.

As with any study, this study has limitations which are worth considering for future research. First, the emission reduction targets and tax rates are based on BAU projections. However, the actual trend of emissions can be higher or lower than the BAU projections depending on factors such as other mitigation strategies, climate change adoption, and the volatility of future fossil fuel prices. The under or overestimated BAU projections will affect the robustness of our results. Second, the design of a comprehensive carbon tax or a policy mix strategy is best incorporated together with revenue recycling strategies but the latter was not undertaken in this study. It can be important to identify different revenue recycling options such as investment of carbon tax revenues in renewable energy generation and adoption, or technological change in the electricity generation mix to examine the economy-wide impacts before deciding on the optimal tax policy. Third, this study did not focus on income distributional effects such as poverty or income inequality impacts of the tax policies. This could be undertaken by relaxing the model assumption of a representative household to incorporate data on income deciles from the household survey for analysis.

APPENDIX



Source: Burniaux and Truong (2002).

Fig. A1. The GTAP-E model capital-energy composite structure.

Table A1
Regional and sectoral aggregation.

Aggregated Regions	Countries Included	Aggregated Sectors	Commodities Included
1. Sri Lanka		1. Coal	Coal mining
2. India		2. Oil	Crude oil
3. Pakistan		3. Gas	Gas manufacture, distribution
4. Bangladesh		4. Oil products	Petroleum, coal products
5. Nepal		5. Electricity	Electricity
6. Rest of South Asia		6. Forestry	Forestry
7. Oceania	Australia, New Zealand, Rest of Oceania	7. Agriculture	Paddy rice, Wheat, Cereal grains nec[1], Vegetables, fruits, nuts, Plant based fiber, Crops nec[1] Vegetables, fruits, nuts, Plant based fiber, Crops nec, Oil seeds, Sugar cane, sugar beet, Plant-based fibers, Cattle, Sheep, Goats, Horses, Animal products, Raw milk, Wool, Silk-worm cocoons, Meat: Cattle, Sheep, Goats, Horses, Fishing
8. East Asia	China, Hong Kong, Japan, Korea, Mongolia, Taiwan, Brunei Darussalam, Rest of East Asia	8. Energy intensive industries	Chemical, rubber, plastic products, Mineral products nec, Ferrous metals, Metals nec.
9. Southeast Asia	Cambodia, Indonesia, Lao Republic, Malaysia, Philippines, Singapore, Thailand, Vietnam, Rest of Southeast Asia	9. Other industries and services	Meat: cattle, sheep, goat, horse. Meat products nec, Vegetable oils and fats, Dairy products, Processed rice, Sugar, Food products nec, Beverages and Tobacco products, Textiles, Wearing apparel, Leather products, Wood products, Paper products, publishing, Metal products, Motor vehicles and parts, Transport equipment nec, Electronic equipment, Machinery and equipment nec, Manufactures nec, Water, Construction, Trade Transport nec, Sea transport, Air transport, Communication, Financial services nec, Insurance, Business services nec, Recreation and other services, Pubadministration/Defense/Health/Education, Dwellings.
10. North America	Canada, United States of America, Mexico, Rest of North America		
11. Latin America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Dominican Republic, Jamaica, Puerto Rica, Trinidad and Tobago, Caribbean.		
12. European Union 25	Austria, Belgium, Cyprus, Czech Republic, Denmark, Germany, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherland, Poland, Portugal, Slovenia, Slovakia, Spain, Sweden, United Kingdom		
13. Sub-Saharan Africa	Benin, Burkina, Faso, Cameroon, Cote d' lvoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa, Botswana, Namibia, South Africa, Rest of South African Customs		
14. Middle East and North Africa	Egypt, Iran, Morocco, Tunisia, Turkey, Rest of North Africa, Rest of Western Asia.		
15. Rest of the World	Switzerland, Norway, Rest of EFTA, Albania, Bulgaria, Belarus, Croatia, Romania, Russian Federation, Ukraine, Rest of Eastern Europe, Rest of Europe, Kazakhstan, Kyrgyzstan, Rest of Former Soviet Union, Armenia, Azerbaijan, Georgia.		

Note: [1]stands for not elsewhere classified.
Source: Authors' aggregation using GTAP database Version 9.

Table A2
Base year (2011) tax rates on private consumption and government. Purchases in Pakistan.

Sector	Ad valorem Tax (%)			
	Private Consumption		Government Consumption	
	Domestic	Imports	Domestic	Imports
Agriculture	0.00	0.00	0.00	0.00
Forestry	0.00	0.00	0.00	0.00
Coal	−7.45	−28.23	0.00	0.00
Oil	−1.50	−18.98	0.00	0.00
Gas	−10.14	−28.12	3.45	0.00
Oil products	37.78	37.78	0.00	0.00
Electricity	−9.00	−28.10	−0.54	0.00
Energy Intensive Industries	0.18	1.66	−0.06	−0.33
Other Industries and Services	0.00	−0.08	0.00	0.37

Note: A positive (negative) value is a tax (subsidy).

Table A3
Base year (2011) tax rates on firms' domestic and import purchases in Pakistan.

Sector	Ad valorem Tax on Firms' Domestic Purchases (%)								
	Agriculture	Forestry	Coal	Oil	Gas	Oil products	Electricity	Energy Intensive Industries	Other Industries and Services
Agriculture	0	0	0	0	0	0	0	0	0
Forestry	0	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	−1.49	−5.37
Oil	0	0	0	0	0	0	0	0	−6.31
Gas	0	0	0	0	0	0	0	0	0
Oil products	0	0	0	0	0	0	0	0	0
Electricity	−5.48	−0.85	0	0	0	0	0	0.47	−1.42
Energy Intensive Industries	0	0	0	0	0	0	0	0	0
Other Industries and Services	0	0	0	0	0	0	0	0	0
Sector	Ad valorem Tax on Firms' Import Purchases (%)								
	Agriculture	Forestry	Coal	Oil	Gas	Oil products	Electricity	Energy Intensive Industries	Other Industries and Services
Agriculture	0	0	0	0	0	0	0	0	0
Forestry	0	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	−10.74	0
Oil	0	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0	0
Oil products	0	0	0	0	0	0	0	0	0
Electricity	−13.79	−6.06	0	0	0	0	0	−10.23	−12.35
Energy Intensive Industries	0	0	0	0	0	0	0	0	0
Other Industries and Services	0	0	0	0	0	0	0	0	0

Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.econmod.2018.06.014.

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